ICSMET 2019 Coventry

Go Green Go Digital (GGGD): An applied research perspective toward creating synergy of crypto-mining and sustainable energy production in the UK

Dr Dennis Chapman

[1] *Faculty of Management and Leadership, CU Coventry, 8 Mile Lane, Coventry, CV1 2TU*

DO NOT CITE WITHOUT EXPLICIT CONSENT FROM THE AUTHOR
Email: ac1453@coventry.ac.uk

Abstract: Despite announcing a climate emergency and the subsequent promise to go carbon neutral by 2050, UK targets for climate change are insufficient to effect the radical changes necessary to reverse the imbalance in the environment caused by human activity. This is due in large part to the high cost to profit ratio of sustainable energy production; profitability of solar, wind, geothermal, wave and other green energies is only realised after significant capital investment and a long gap period to breakeven (up to 10+ years). This means that only a few players will have both the capital and time to make a profit, leaving unsustainable energy as the cheaper (and more feasible) option. Ergo, without a short-term profit incentive, the sustainable energy industry is unlikely to grow quickly enough to counter the climate emergency that the world now faces. As the UK government has decided not to subsidise green energy until 2025, radical ideas which incentivise commercial activity toward investment in sustainable energy production must be explored. This paper suggests a specific implementation of the digital economy with a strong profit motive for green investors. Utilising a multi-disciplinary method of research, this paper argues from an applied computer science perspective that green crypto-mining can provide essential funding from the early stages of sustainable energy planning all the way to the deployment of a full crypto-mining operation scalable to the investment capabilities of the organisation. This solution works on two levels: 1. Convert sustainable energy production directly to capital through crypto-mining and 2. Grow the digital industry, in particular crypto-mining, in the UK to increase demand for sustainable energy, and as a result reduce the costs of going green for all energy consumers. The aim, therefore, is that renewable energy outcompetes unsustainable energy on a free market basis in the UK, thereby accelerating the green revolution.

– **Keywords:** Sustainable energy, renewable energy, crypto-mining, CPU mining, crypto-currency, digital economy, free market, carbon neutral, government subsidies, sustainability funding, profitability and sustainability

"For however many things have a plurality of parts and are not merely a complete aggregate but instead some kind of a whole beyond its parts, there is some cause of it since even in bodies, for some the fact that the there is contact is the cause of a unity/oneness while for others there is viscosity or some other characteristic of this sort."
--Aristotle, Metaphysics 8.6 [1045a]

Introduction

GGGD is an augmentation of the renewable energy power plant powering passively-cooled, CPUs capable of converting electrical energy into virtual currency using a free, open source mining algorithm, i.e. crypto-mining. Moreover, once all of the hardware is installed, there are only marginal costs for the life of the system. In addition, GGGD has wide portability insofar as harvested free energy can be redistributed back to the grid and the CPUs at any ratio depending on market conditions. In fact, CPUs need not only mine crypto-currency; CPUs can be sub-contracted to customers such as the NHS, NASA, ESA, SETI, or any other data-centred organisation located around the world with complex algorithms to solve.

Fig. 1. Simplified GGGD Model.

Simplified GGGD model of wind, solar, crypto-mining, and Monero (XMR) virtual currency production.

Source: author's creation

Government money to renewable energy is insufficient to create the incentives needed for a radical change in the markets toward self-sustaining / self-sufficient systems. Instead, public funds are redistributed to unsustainables such as hydraulic fracturing, i.e. fracking, which have documented histories of damaging the environment and poisoning the water supply in the United States (Holloway 2018; Malin and DeMaster 2015; Zhang and Yang 2015; Kuwayama 2015),[i] or nuclear, which suffers not only a public relations problem after such disasters as Chernobyl and Fukushima (Wheatley, Sovacool and Sornette 2016), but also a "decline of the average selling price on the margin of safety" (Deutsch, Fiáith, Virág et al. 2018), meaning simply that nuclear power is both unpopular and expensive.

GGGD offers a solution which incentivises the markets to invest concurrently into two technologies – renewable energy and computing power – which together this paper argues can spark a dot-com style hyperbolic inflation of investment in its fast and broad adoption (See Appendix D). The positive side effect is a significant increase in dynamically controlled energy capacity which can be used to stabilise the UK's power grid as it transitions to 100% renewables (Kroposki, Johnson, Zhang et al. 2017; Short and Infield 2007).

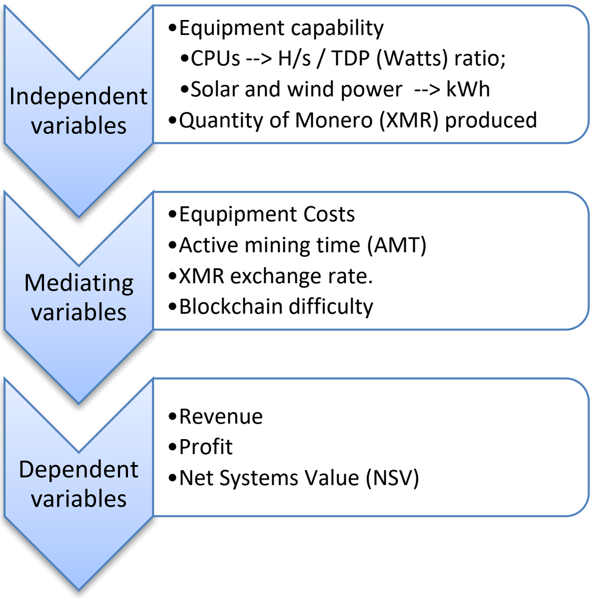
The hypothesis of this paper is that renewable energy combined with crypto-mining will, as a combined force, breakeven earlier in its lifecycle than either technology deployed alone (with market conditions a mediating factor). The evidence for this statement is well-documented in each independent technology's tested and benchmarked capabilities (See Appendix C). The design in this paper is a particular iteration of their combination for the purposes of moving to the next stage after this paper: building the prototype.

Methods

The methods of this paper are investigatory, broadly surveying existing data on renewable energy and crypto-mining. The academic foundation is multidisciplinary with concepts in physics, computer science and economics all playing a role in thought-testing and real-world application.[ii] The primary research is independently-funded, with IT facilities support from Coventry University, who authorised research to be conducted on-site. All primary and secondary research complies with university ethics.

First, the primary research conducts an open-ended interview with a CEO of a virtual currency mining firm to evaluate the feasibility of GGGD against the experience of an existing global operation. Second, the researcher selects and benchmarks various crypto-currencies to determine whether it is more cost effective to mine with CPUs, GPUs or ASICs. Third, the particular CPU and cooling options are selected based on the ratio of power (hash rate) to efficiency (equipment and electricity costs). And finally, the combination of wind and solar are selected to power the crypto-mining rig based on scalability and equipment costs.[iii]

Fig. 2. Operationalisation of GGGD.



Causal Assumptions:

1. The higher the H/s / TDP ratio, the higher the XMR produced;
2. The higher the number of XMR produced, the higher the revenue;
3. The higher the blockchain difficulty, the fewer the XMR are produced.[iv]
4. The more energy (kWh), the higher the quantity of CPUs that can be installed;
5. The higher the quantity of CPUs installed, the higher the quantity of XMR produced;
6. The higher the AMT / AP, the higher the revenue;
7. The lower the setup costs, the higher the profit (costs are subtracted from revenue);
8. The higher the exchange rate of XMR, the higher the profit;
9. The more profitable the system, the higher the NSV.

Source: author's creation

Table 1. Preliminary forecasted profits from mining with AMD Ryzen 9 3900x.[v]

CPU: AMD Ryzen 9 3900x

Hashrate:	11765 hashes/second
Average yearly reward:	24.74 XMR 1,967.30USD
Energy requirements:	105 Watts[vi]

Time Frame	XMR Coins	Profit (in USD)
Hourly	0.00282	$0.22
Daily	0.06778	$5.39
Weekly	0.47447	$37.73
Monthly	2.03343	$161.70
Annually	24.74	$1,967.30

Source: Adapted from Coinwarz.com (2019)

Scientific Theory

The following scientific theories together come together to support the GGGD design:

(1) Second law of thermodynamics:

Relative rate of entropy is reduced by cutting out stages in energy transfer (to the grid) and storage (in batteries); electricity goes straight to the appliance (DC current). Mechanical and chemical engineering have an inherent prerogative to waste less as a matter of design (Li 2018; Kjelstrup, Bedeaux and Johannessen 2010).

(2) Fluid dynamics:

Passive Cooling Units (PCUs) are affordable, are low maintenance and have long lifecycles with future compatibility with upgraded CPUs. Their one off marginal cost is further mitigated by indefinite reusability as sustainable CPU coolers (Septiadi, Ula, Wulandan et al. 2019; Heydari et al. 2012).

(3) Moore's Law:

Modern processors have reached the ceiling of Moore's Law classically-understood; however, Moore's Law is still relevant in new CPU designs which incorporate multi-cores and processor supplementary capability (Flamm 2018; Shalf and Leland 2015).

(4) Dennard (MOSFET) Scaling:

Dennard (MOSFET) scaling is the theory that as the size of CPUs / frequency decreases, frequency / watts increases (Bruni 2017; Dennard, Gaensslen and Rideout 1974).[vii]

General Systems Theory (GST)

The following typology links the scientific theory above with capital production:

(1) "General System Theory . . . is a general science of 'wholeness'":

Integrating two separate technologies – renewable energy and crypto-mining – makes whole a system designed to reduce per capita CO2 output by increasing green GDP.

(2) "There is a general tendency towards integration in the various sciences, natural and social":

GGGD earns profit directly by processing computer algorithms which have an inherent social value, i.e. money. Scientific innovation drives the renewable and digital economies.

(3) "Such integration seems to be centred in a general theory of systems":

GGGD is based on science fundamentals. In particular, the scientific notion of rate of entropy: efficiencies slow the rate of entropy and, in these gains, a profit can be attained.

(4) "Developing unifying principles running 'vertically' through the universe of the individual sciences, this theory brings us nearer to the goal of the unity of science":

GGGD generates profit from free energy making money for the proprietor without doing harm to the environment and furthermore builds green infrastructure which becomes cheaper to build as it grows.

(5) "This can lead to a much-needed integration in scientific education":

Understanding the connection of power to the growing digital industry, as well as the energy gap the UK inevitably faces, is important for students of all academic disciplines.

Source: Adapted from Bertalanffy (1968)

Environmental emergency

As of writing up this paper for this ICSMET conference, the Amazon and Brazilian rainforests—the two lungs of the Earth providing Notwithstanding political conflagration of the Amazon fires, climate change is also to blame; as the weather becomes more extreme, resultant heat waves create arid conditions that help spread fires all around the globe (citation). Moreover, global demand for plastic, meat and fossil fuel drives human caused climate change not just in Brazil, but also in all corners of the globe that practice GDP growth at the expense of the environment (citation).

The environmental emergency means that the classical model of productivity—increasing energy input to increase productivity output—is unsustainable when the input costs include destruction and pollution of the environment.[viii] The short-term profits from slash and burn are a case in point in non-sustainability (citation); however, other businesses such as fracking cause high cumulative damage to the environment by consuming resources and polluting the environment for marginal gains.

To solve the problem of an unsustainable economy, then, requires a new perspective of production, both in terms of transitioning to a knowledge economy and in terms of seeking to consume less energy whilst increasing economic productivity. This is feasible specifically in computing which produces value as a function of the speed and complexity of processing algorithms times the value of this information [Quantity (Q) times Value (V)]. However, this is still not enough for long-term sustainability, as it does not factor in environmental damage.

NSV

It is not just enough to be profitable in the classical sense; environmental costs need to be accounted for in the Net Present Value (NPV). To do so, NSV accounts for the time cost of pollution (TCP) emitted by a company in the conducting of its day-to-day operations. It is a novel concept to account for, let alone tax, a company based on its actuarial long-term damage to the commons (citation). In short, a business may be highly profitable on its balance sheet, but when environmental damage is factored into the equation, a business will find it is much less profitable or in fact operating at a macro-environmental loss. Low NSV business models must be eliminated to stop human caused climate change.

In terms of climate change, the macro-environment is the planet Earth, not just the walls—bricks or virtual—which make up a company's operations. NSV is therefore determined by balancing the long-term, macro environmental costs of a business against its short-term economic profits. The result is a finding that many companies' profits are more a function of their unaccounted for costs to the environment (citation) than innovative management (citation). For example, plastic produced today will continue to cost the environment 1000s of years from now. Plastic in the food chain could theoretically filter through hundreds or thousands of animals before breaking down, making them sick or killing them in the process (citation).

Figure 3. Net System Value Formula.

$$(QV + C) / T = N.S.V.$$

Key: Q = Quantity; V=Value; C=Cost; T=Time; N.S.V.=Net Systems Value

- **Q**uantity: Forecasted number of economic units produced
- **V**alue: Forecasted value of the economic unit produced
- **C**ost: Variable costs + Taxes + Liabilities + Environmental costs (over total lifecycle of pollution)
- **T**ime: Accounting period
- **N.S.V.**: Net Systems Value

Source: Author's creation

In short, NSV, as opposed to NPV, measures the economic output of the system by adding all costs, financial and environmental, over the entire lifecycle of the product and the product's waste, from manufacturing to consumption to disposal, leaving a figure that reflects a company's true profit when this additional "environmental tax" is applied.[ix]

Applying this model to products and industries can be done be considering four operational models of business based on their output / input ratio.

Table 2. Four typologies of variable input and output operationalised as energy and profit respectively.

		Output +	Output -
Input	+	Cheap / high quantity / energy intensive / scalable / unsustainable Example: Incandescent light bulb	Expensive / low quantity / energy intensive / not scalable / unsustainable Example: ASIC mining
Input	-	Cheap / low quantity / energy saving / scalable / sustainable Example: LED lighting	Cheap / high quantity / energy saving / not scalable / sustainable Example: CPU mining

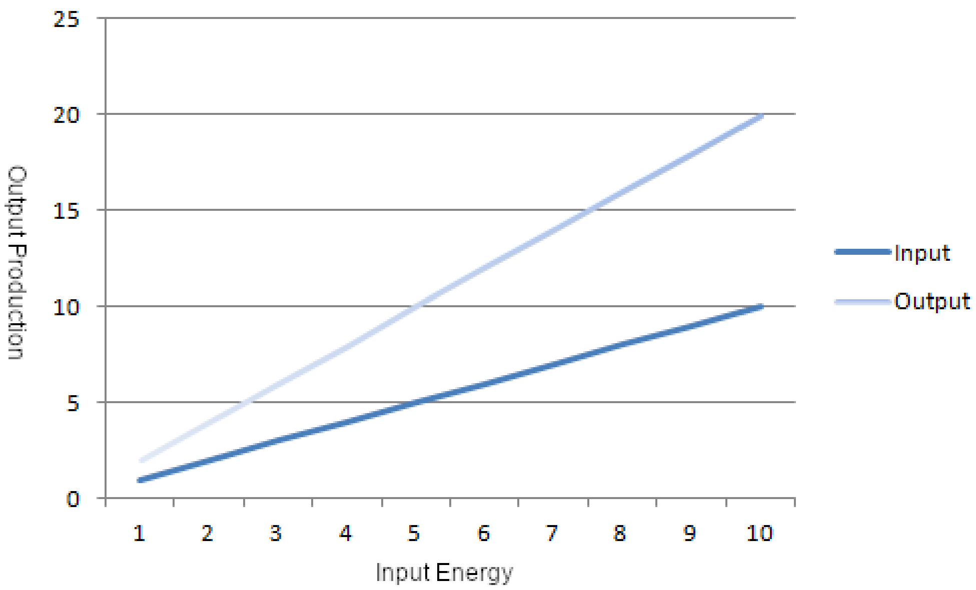
Source: Author's creation

Input (+) / Output (+)

High input / high output creates additive growth with the only limitations being time, capabilities and environmental tolerances. For example, franchises such as McDonalds create additive growth as each new business franchise (when successful) adds to the overall profits of the company. The largest and most successful additive growth companies create ever fine-grained business models with all aspects of the business designed and tested over long enough periods that profit becomes predictable within small margins of error.

The mathematical formula for input / output systems is simply: f(x) = x. The variable x in this case represents the ratio of output performance / input energy. To increase the value of x, one scales the input energy, producing predictable additive gains, i.e. profit.

Figure 4. Additive growth in input / output systems.



Source: Author's creation

Figure 4 above represents additive growth, whereby scaling the business is a function of output / input capacity times market demand. Whilst this is "tried and true" business model, the limitation of this model is that to output more one has to input more. This invariably leads to a shortage of input energy when demand exceeds capacity. Moreover, additive business models not only scale profits, but also scale pollution, which negatively affects the NSV, as opposed to NPV, of the company.

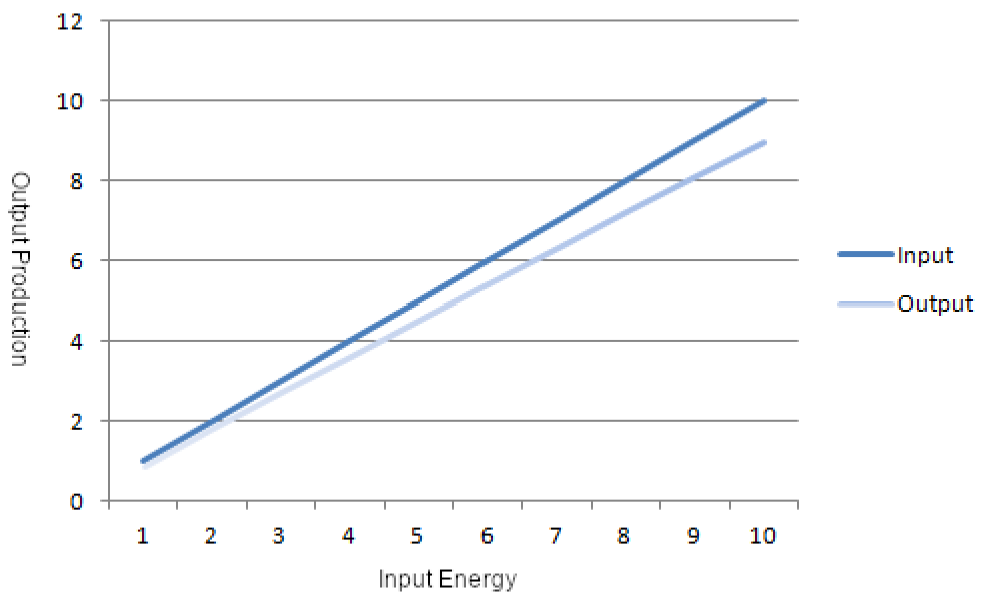
Input (+) / Output (-)

High input / low output creates additive losses either as diminishing returns or in the case of a business model which simply does not produce enough profit to breakeven within the required accounting period. The diminishing returns model is what currently characterises the home solar industry which profits the energy companies first and foremost with customers lucky to breakeven on their investment over ten years. In fact, it is becoming clear that the consumer solar market is not as profitable as once thought for the consumer.

> "Many people took out loans to pay for panels on the promise they would save thousands of pounds in electricity costs and make money generating power. They say they have not had the expected savings, and the Financial Services Ombudsman has had 2,000 complaints. Barclays Bank has put aside £38m to deal with potential claims" (BBC News 2019).

There are two reasons for diminishing returns in the solar market. First, customers are only promised at best a 70% rebate on their electricity bill (citation). The researcher called several solar companies for a quote regarding his own house to receive the latest offers and the 70% is standard across the industry. This means that if a customer pays £600 / year in electricity bills and pays £10k for the solar panels, it would take 23 years to pay it off, the same time it takes to pay off a mortgage (Solar price survey 2019). A breakeven analysis of home solar versus GGGD will take place later in the paper, but for now it is enough to say that with such poor ROI and without government subsidy, the solar market in the UK will not accelerate fast enough to counter climate change, as there is little financial incentive for the customer; few people have the money to pay up front.

Figure 5. Diminishing returns in input output systems.

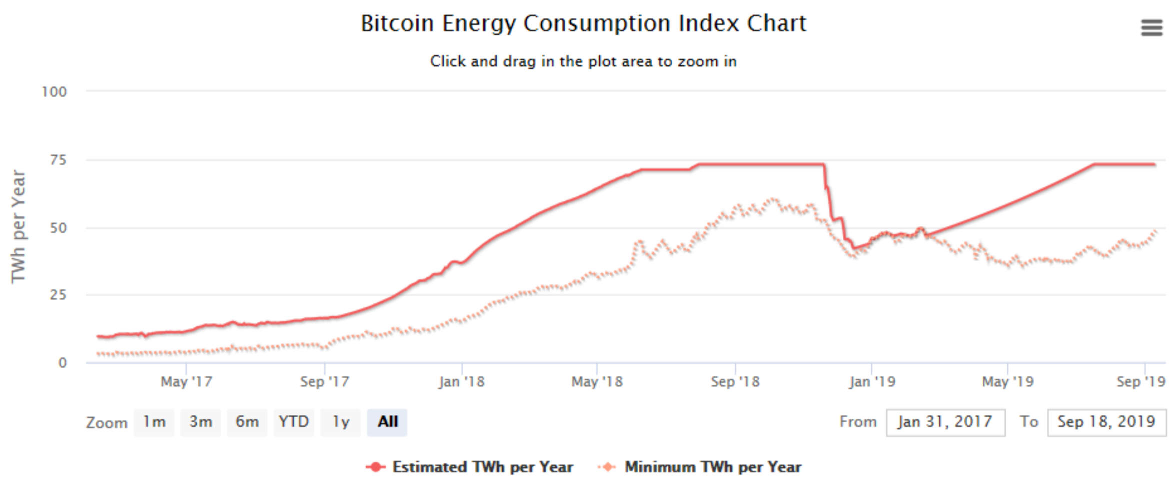


Source: Author's creation

Figure 5 above represents any productivity system whose long-term output production never reaches breakeven due to marginal returns and increasing costs, such as technology deprecation. It is the reality of the above graph that was behind early government subsidies of solar, to provide enough money to move the bottom line (output) above the top line (input) in order to incentivise consumer spending; efficiency gains through better engineering of the technology are not enough alone to make solar profitable for the consumer due to political and economic obsticles (Kabir, Kumar, Kumar et al. 2018; McKenna, Pless and Darby 2018).

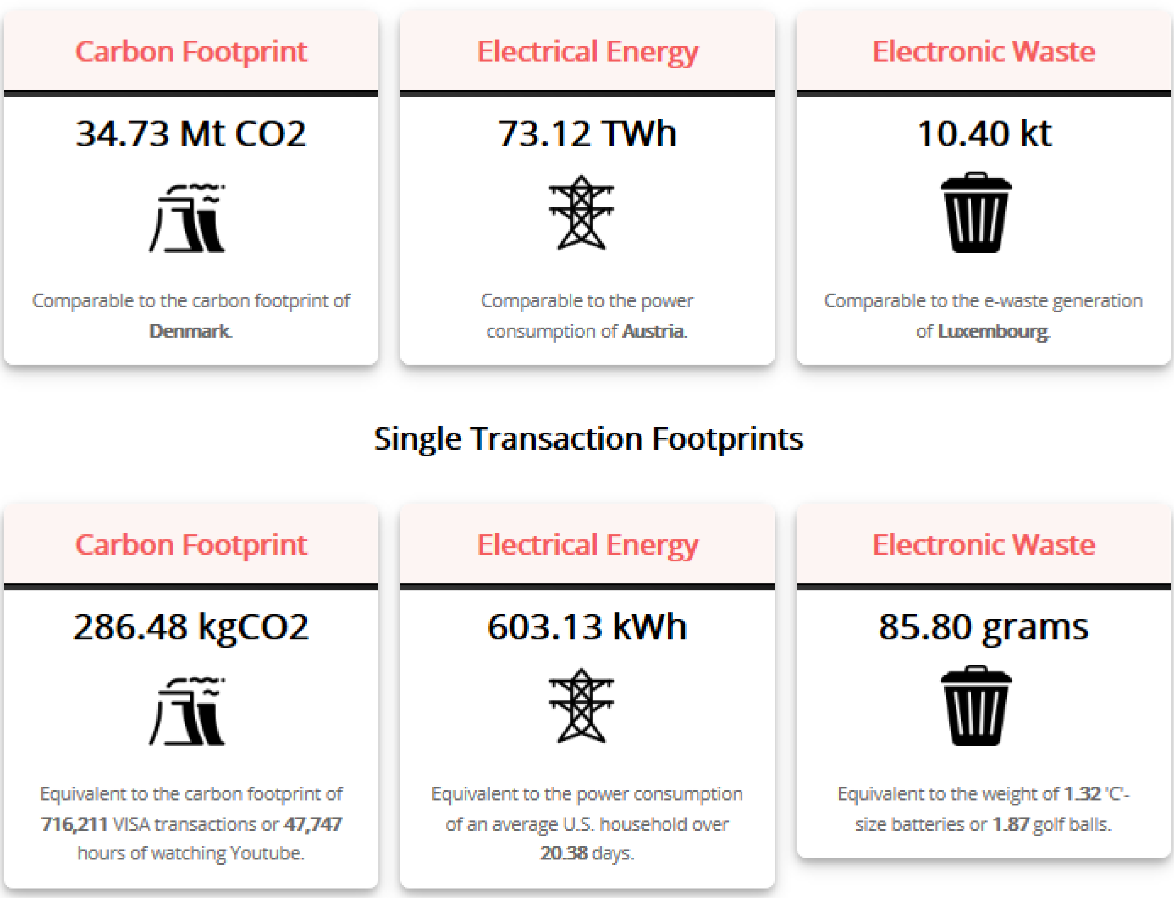
ASIC mining, as opposed to CPU mining, also fits the diminishing returns profile when N.S.V. is factored into the equation. The Bitcoin energy consumption index shows how energy intensive Bitcoin production is, and since most Bitcoin machines are powered by unsustainable energy, their net contribution to climate change is not insignificant. In fact Bitcoin mining has the same carbon footprint as that of the country of Denmark, and consumes the equivalent energy of Austria (73.12 TWh) (Digiconomist 2019).

Figure 6. Bitcoin (ASIC mining) energy consumption.



Source: Adapted from Digiconomist.net (2019)

Figure 7. Bitcoin (ASIC mining) carbon footprint.



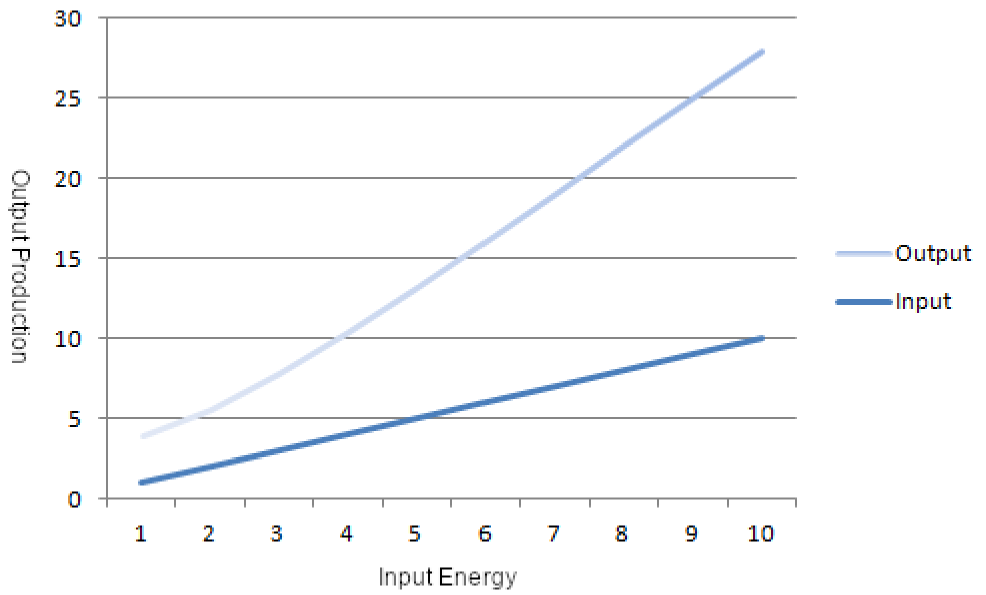
Source: Adapted from Digiconomist.net (2019)

See Appendix F. for more detailed specifications.

Input (-) / Output (+)

Low input / high output systems create exponential growth of output production by creating systems, processes and algorithms that result in intellectual property, be that the sequencing of the human genome or discovering the next crypto-currency block, as well as durable assets. From sequencing DNA to processing astronomy data on black holes to mining crypto-currency, the value of computing is in its ability to complete complex equations in short time-frames, i.e. low energy / high frequency systems (Flamm 2018; Bruni 2017; Dennard 1974). GGGD, however, does more by augmenting renewable energy with durable hardware that saves money for every subsequent lifecycle after the initial investment.

Figure 6. Exponential growth in input / output systems.



Source: Author's creation

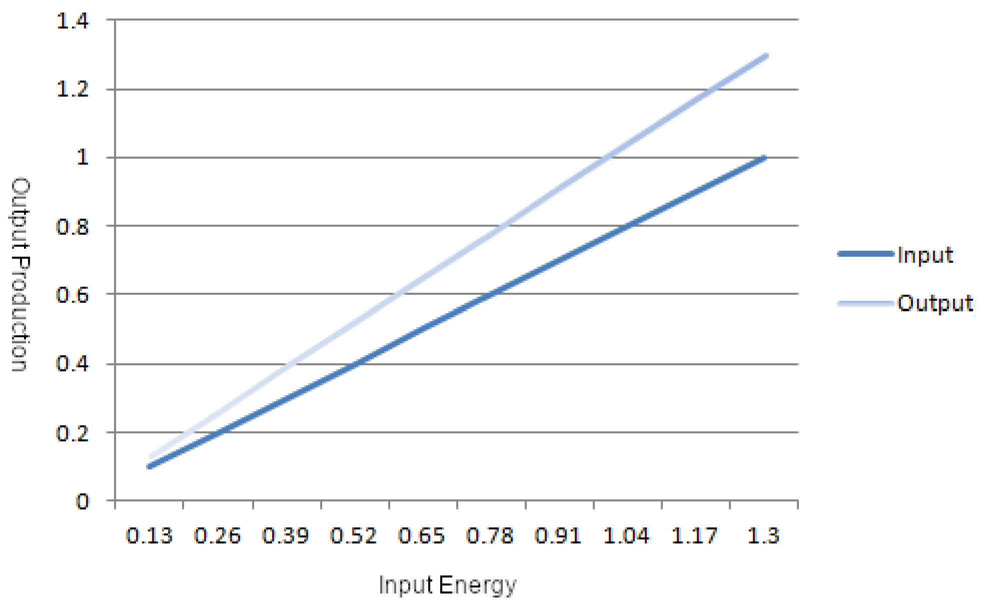
Figure 6 above represents any productivity systems whose long-term growth only increases the profit margin due to the durability of base components of the system with new lifecycles of the product limited to modular upgrades. GGGD does this by requiring only a one off investment in a power plant and passive cooling with upgrades of the CPU the core requirement, followed by the motherboard. All other components of the system, including the renewable power plant and auxiliary hardware are durable (10+ years).

In order for a productivity system to create clean exponential growth (a high NSV score), the system must not only provide economic benefit, but also must emit as near zero environmental pollution as possible, thereby not only benefiting the economy, but also growing sustainable development infrastructure in the process. This process results in a "virtuous circle" whereby all stakeholders, including the planet Earth, benefit from continued growth (Lucas, Francés and González 2016; Bogliacino, Lucchese, Nascia and Pianta 2016).

Input (-) / Output (-)

Low input / low output systems create marginal growth by limiting supply and demand to a small target audience. Scholars call this "doing less with less", a mentality which can be applied to industries from medicine (Hodgson 2016) to military (Robinson 2005) and which is especially important to consider with the inevitable retraction of the economy caused by Brexit . Out of all the options presented, low input / low output systems are the most sustainable and are therefore arguably the system by which humans should live in the future, that is, using small amounts of power and producing small amounts of products (this does not have to limit effectiveness). However, short of a global revolution overthrowing the ancient regime in some sort of environmental coup, or a global catastrophe such as a solar flare that destroys all electronic systems, doing less with less could not be immediately implemented worldwide. Creating a profit incentive is way to make the transition without causing social disruption.

Figure 7. Doing less with less in input / output systems.

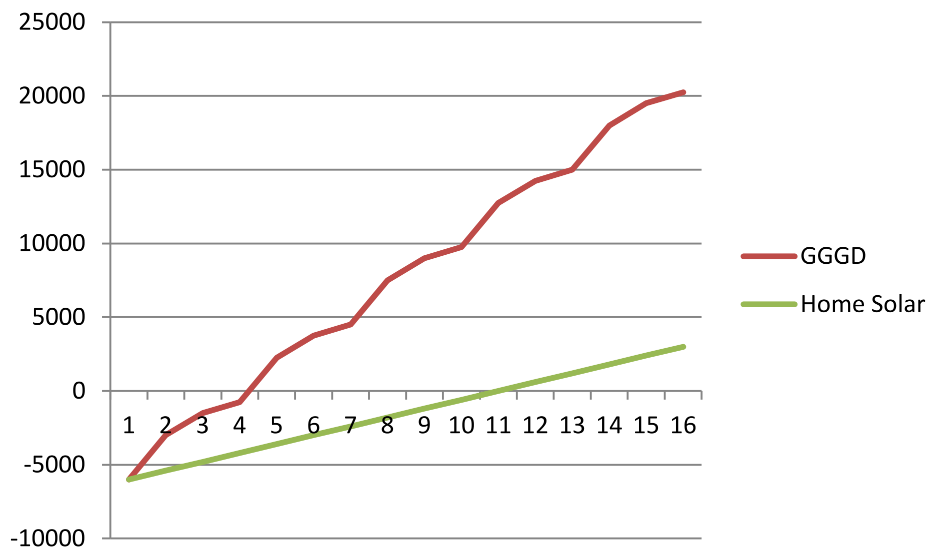


Source: Author's creation

Figure 7. above represents any system with nominal or marginal profit whereby energy input roughly equals output productivity. As a population grows and its needs grow with it, scalability is a function of basic subsistence without a luxury market to create artificial demand.

There are examples around the world of low input / low output systems. The Amish are a prime example of this economic method. Going back to the discussion of our rainforests being slashed and burned, author's have suggested that local families that clear rainforest can create sustainable agriculture without the need for further clearance (Tremblay, Lucotte, Reveret et al. 2014;). Ideally, the entire planet would simple "do less with less", thereby decreasing demand for luxury products and increasing subsistence living, including local and family supply chains.

Solar Homes versus GGGD breakeven



Research extension and application

The research in this paper focuses on the UK as the location and moreover introduces specific hardware for the sake of establishing a commercial benchmark for investors. However, location and hardware can be varied depending on a number of situations. For example, the research could be applied to Africa to increase sustainable development, leaving behind renewable energy infrastructure which can be used to power homes.

Other potential variations and applications:

- Using any single or combination of green energy types depending on resources available in a country
- Using other OEM hardware combinations depending on cost and supply chain availability
- Mining other CPU currencies other than Monero (Monero is surmised to be the leader in CPU mining, but other established CPU currencies would do well). For example, if the UK government is serious about creating its own crypto-currency, it might consider allowing the public to mine it using the system developed in this paper.
- Monetising CPUs by solving algorithms for science instead of crypto-currency. Labs already outsource their algorithms to home users who can earn credit for their work.
- Scaling up and renting CPU power for mining (this type of business is already established, although not restricted to CPU mining)

This is not an exhaustive list of alternative setups and applications, but the list shows the great agility potential of GGGD to transform economies and energy production worldwide.

Research scope

There are scope limitations to this paper. First, space limitations prevent a comprehensive comparison of all competing technologies which could potentially be used to power GGGD. However, the prototype system designed here is enough to gain the perspective needed with a balance of technical feasibility and strategic coherence. To survey all theory, formulas and specifications would require a monograph. However, this paper is a starting point for building these systems and for a small business provides enough information to get started.

Moreover, not all of the results of primary research could be included due to space limitations. However, this research was primarily feasibility research to test existing benchmarks published online. In future research, testing of

Future research would build the design and test the theories presented here over the proposed three year lifecycle. If successful, it would mean that the research prototype could be rolled out to the public.

Conclusion

Bibliography

- Amrouch, H. Pahwa, G., Gaidhane, A.D., Henkle, J. and Chauhan, Y.S. (2018) "Negative Capacitance Transistor to Address the Fundamental Limitations in Technology Scaling: Processor Performance". *IEEEAccess* [online] Available at: https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8467321 [19 Jul 2019]
- Aristotle and Ross, W.D. (2014) *Metascience*. Stilwell: Neeland Media LLC.
- Bitcoin energy consumption index (2019) Bitcoin energy consumption index". [online] Available at <https://digiconomist.net/bitcoin-energy-consumption> [10 Sept 2019]
- Beech, M. (2016). *Terraforming*. Springer: New York
- Bitcoin energy consumption index (2019) Bitcoin energy consumption index". [online] Available at <https://digiconomist.net/bitcoin-energy-consumption> [10 Sept 2019]
- Bogliacino, F., Lucchese, M., Nascia, L. and Pianta, M. (2016) "Modelling the virtuous circle of innovation: A test on Italian firms". ISIGrowth [online] Available at <http://www.isigrowth.eu/wp-content/uploads/2016/01/working_paper_2016_3.pdf> [10 Sept 2019]
- Bruni, J. (2017) "Why does low frequency have high energy and high frequency have low energy?" *Quora* 5 Oct 2017 [online] Available at https://www.quora.com/Why-does-low-frequency-have-high-energy-and-high-frequency-have-low-energy [30 Jul 2019]
- Chirgwin, B., Plumpton, C. and Kilmister, C. (2014) *Maxwell's Equations and Their Consequences*. Kent: Elsevier Science
- CoinWarz.com (2019) *Estimated Expected Cryptocurrency Earnings*. [online] Available at https://www.coinwarz.com/calculators/monero-mining-calculator/ [30 Jul 2019]
- Dennard, R.H., Gaensslen, F., Rideout, V., Bassous, E. and LeBlanc, A. (1974) "Design of ion-implanted MOSFET's with very small physical dimensions". *IEEE Journal of Solid-State Circuits* 9 (5), 256-268
- Deutsch, N., Fiáth, A., Virág, M. and Berényi, L. (2018) "Sensitivity of the margin of safety: A nuclear power generation case" *International Journal of Power Systems* 3, 1-10
- Frank, D.J, Dennard, R.H., Nowak, E. Solomon, P.M., Taur, Y. Wong, H.P. (2001) "Device Scaling Limits of Si MOSFETs and Their Application Dependencies". *Proceedings of the IEEE* 89 (3), 259-288
- Feldman, M. (2019) "UK's ARCHER2 supercomputer aims squarely at the CPU Bullseye". *TheNextPlatform* [online] Available at https://www.nextplatform.com/2019/03/26/uks-archer2-supercomputer-aims-squarely-at-the-cpu-bullseye/ [17 Jul 2019]
- Flamm, K. (2018) "Measuring Moore's Law: Evidence from Price, Cost, and Quality Indexes". *NBER Working Paper No. 24553* [online] Available at https://www.nber.org/papers/w24553 [30 Jul 2019]
- Gómez-Leal, I., Kaltenegger, L., Lucarini, V. and Lunkeit, F. (2018) "Climate Sensitivity to Carbon Dioxide and the Moist Greenhouse Threshold of Earth-like Planets under an Increasing Solar Forcing". *The Astrophysical Journal* 869 (2), 1-2
- Hanson, E. (2019) "Solar Panels: Thousands of customers complain". BBC News [online] Available at <https://www.bbc.co.uk/news/uk-england-49566130> [10 Sept 2019]
- Hodgson, Humphrey (2016) "Doing less with less". Clinical Medicine, 16, 5, 403-404
- Holloway, M.D. (2018) *Fracking: Further investigations into the environmental consideration and operations of hydraulic fracturing*. London: Wiley
- Kabir, E., Kumar, P., Kumar, S., Adelodun, A. and Kim, K.H. (2018) "Solar energy: Potential and future prospects". Renewable and Sustainable Energy reviews 82, 894-899

- Kasting, J. (1988). “Runaway and moist greenhouse atmospheres and the evolution of Earth and Venus”. *Icarus* 74 (3), 472-494
- Kjelstrup, S., Bedeaux, D., Johannessen, E. and Gross, J. (2010) *Non-equilibrium thermodynamics for engineers*. London: World Scientific
- Kondepudi, D. (2008) *Introduction to Modern Thermodynamics*. London: Wiley
- Kroposki, B., Johnson, B., Zhang, Y., Gevogian, V., Denholm, P, Hodge, B. and Hannegan, B. (2017) “Achieving a 100% renewable grid”. *IEEE Power and Energy Magazine* (March 2017) [online] Available at https://www.researchgate.net/profile/Bri-Mathias_Hodge/publication/314198578_Achieving_a_100_Renewable_Grid_Operating_Electric_Power_Systems_with_Extremely_High_Levels_of_Variable_Renewable_Energy/links/59e9018faca272bc425f54f3/Achieving-a-100-Renewable-Grid-Operating-Electric-Power-Systems-with-Extremely-High-Levels-of-Variable-Renewable-Energy.pdf [30 Jul 2019]
- Kuwayama, Y. (2015) “Water Quality and Quantity Impacts of Hydraulic Fracturing”. *Current Sustainable/Renewable Energy Reports* 2 (1), 17-24
- Li, K. (2018) *Applied thermodynamics*. Washington, DC: CRC Press LLC
- Lucas, J.N.V., Francés, G.E. and González, E.S.M. (2016) "Energy security and renewable energy deployment in the EU; Liasons Dangereuses or Virtuous Circle?" renewable and Sustainable Energy Reviews, 62, 1032-1046
- Malin, S. A. “A Devil’s bargain: Rural environmental injustices and hydraulic fracturing on Pennsylvania’s farms”. Journal of Rural Studies (1) 13, 1-13
- Marland, G., Boden, T.A. and Andres R. J. (2003) "Global, Regional, and National CO2 Emissions." *In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.*
- McKenna, E., Pless, J. and Darby, S.J. *(2018) "Solar photovoltaic self-consumption in the UK residential sector: New estimates from a smart grid demonstration project". Energy Policy, 118, 482-491*
- Ramirez, R. (2018) “The Moist Greenhouse is Sensitive to Stratospheric Temperature”. *Research Notes of the AAS*, 2 (1), 1-6
- Popp, M., Schmidt, H. and Marotzke, J. (2016). “Transition to a Moist Greenhouse with CO2 and solar forcing”. *Nature Communications*, 7 (1)
- Robinson, Paul (2005) Doing less with less: making Britain more secure. Imprint Academic: Exeter
- Septiadi, W.N., Ula, W.A.W., Wulandan, I.G.A.A.D., Tnunay, I.A. and Murti, M.R. (2019) “Thermal resistance analysis of central processing unit cooling system based on cascade straight heat pipe”. *IOP Conference Series: Materials Science and Engineering* Ser.: Mater. Sci. Eng. 539 012036 [online] Available at https://iopscience.iop.org/article/10.1088/1757-899X/539/1/012036/meta [30 Jul 2019]
- Shalf, J.M., Leland, R. (2015) “Computing beyond Moore’s Law”. *eScholarship.org* 48 (12), 32-41
- Short, J., Infield, D. and Freris, L.L. (2007) “Stabalization of grid frequency through dynamic demand control”. *IEEE Transactions on power systems*, 22 (3), 1284-1293
- Tremblay, S., Lucotte, M., Reveret, J.P., Davidson, R. Mertens, F., Passos, C.J.S. and Romana, C.A. (2014) Agroforestry systems as a profitable alternative to slash and burn practices in small-scale agriculture of the Brazilian Amazon. Agroforest Syst [online] Available at <https://www.researchgate.net/publication/273119662_Agroforestry_systems_as_a_profitable_alternative_to_slash_and_burn_practices_in_small-scale_agriculture_of_the_Brazilian_Amazon> [10 Sept 2019]
- University of Edinburgh (2019) *£79m supercomputer set to boost UK capability*. 11 Mar 2019 [online] Available at: https://www.ed.ac.uk/news/2019/ps79m-supercomputer-set-to-boost-uk-capability [17 Jul 2019]

- Wagner-Tsukamoto, S. (2007) “An institutional economic reconstruction of scientific management: On the lost theoretical logic of Taylorism”. *Academy of management review* 32 (1), 105-117
- Weijdema, E. (2011) *How to calculate electrical costs for cooling and power consumption*. [online] Available at https://vmguru.com/2011/06/how-to-calculate-electrical-costs-for-cooling-and-power-consumption/ [27 Jul 2019]
- Wheatley, S., Sovacool, B.K. and Sornette, D. (2016) “Reassessing the safety of nuclear power”. *Energy Research & Social Science* 15, 96-100
- Zhang, D. and Yang, T. “Environmental impacts of hydraulic fracturing in shale gas development in the United States”. *Petroleum Exploration and Eevelopment* 42 (6), 876-883
- Zentropicmaximillist (2018) "Reply to Jonahar: Should we be concerned about ASICs for Monero?" *Monero* [online] Available at https://www.reddit.com/r/Monero/comments/6vpq08/should_we_be_concerned_about_asics_for_monero/ [16 Jul 2019]

Statistics:

- Auditor General (2016) “Nuclear Power in the UK”. National Audit Office 13 Jul 2016 [online] Available at https://www.nao.org.uk/wp-content/uploads/2016/07/Nuclear-power-in-the-UK.pdf [24 Jul 2019]
- National Statistics (2019) “2017 UK Greenhouse Gas Emissions, Final Figures.” *Department for Business, Energy & Industrial Strategy* [online] Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/776085/2017_Final_emissions_statistics_-_report.pdf [15 Jul 2019], 1-23
- GOV.UK (2018) “Historical electricity data: 1920 to 2017”. *Department for Business, Energy & Industrial Strategy* [online] Available at https://www.gov.uk/government/statistical-data-sets/historical-electricity-data [15 Jul 2019]
- Gridwatch.co.uk (2019) *GB Electricity National grid CO2e Output per Production Type*. [online] Available at http://gridwatch.co.uk/co2-emissions [24 Jul 2019]
- Roberts, T. and Robert, H. (2019) “Nuclear electricity in the UK”. *Special feature - Nuclear electricity in the UK* [online] Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/789655/Nuclear_electricity_in_the_UK.pdf [03 July 2019]

Videos:

- Knight, S. (2019) “Passive cooling with Intel’s Core i9-9900K CPU”. *Techspot* 12 Mar 2019 [online] Available at https://www.techspot.com/news/79149-passive-cooling-intel-core-i9-9900k-cpu.html [16 Jul 2019]

Patents:

- Heydari, A., Gross, K.C. (2012) “Modular absorption heat sink devices for passive cooling of servers and other electronics”. *US Patent 8,276,394* [online] Available at https://patentimages.storage.googleapis.com/90/a3/56/1c45135a13ad32/US8276394.pdf [30 Jul 2019]

Primary research:

- Solar price survey (2019) Likely returns on a 2-3 bedroom terraced house. Price survey conducted from Jul-Aug 2019 with five top solar providers.
- Interviews conducted with crypto-mining CEO (2018) Feasibility research conducted from Jan –Jun 2018.
- Amazon AWS Bitnami Linux server (2017-2018) Headless browsing to mine Monero using unmetered CPU, thereby not breaking Amazon's Terms of Service which prohibits installing mining software.
- Monero software mining on native machine (2017-2018) Testing of passive cooling augmentation of PC

List of Abbreviations:

GGGD: Go Green Go Digital

ASIC: Application Specific Integrated Circuit

AMT: Active mining time

NSV: Net systems value

CPU: Computing processing unit

GPU: Graphical processing unit

ASIC: Application specific integrated circuit

XMR: Monero (virtual currency)

PCU: Passive cooling unit

AMT: Active Mining Time

AP: Accounting Period

NHS: National Health Service

XMR: Currency symbol for Monero crypto-currency

TDP: Thermal Design Power

UK: United Kingdom

GST: General Systems Theory

NASA: North American Space Agency

ESA: European Space Agency

NPV: Net Present Value

C2C: Cost to commons

TCP: Time Cost of Pollution

Appendix B. GGGD mining rig core components: CPU, motherboard and passive cooling (All prices are estimates based on pricing as of 30 Jul 2019)

Passive cooling (£100)

SilverStone Heligon HE02 Fanless CPU Cooler
95W (Fanless) / 150W (with 120mm fan > 900 RPM in case), over 150W with 120mm fan on top

Image source: Graphicscardhub.com (2019)

Motherboard (£100)

Gigabyte X570 GAMING X ATX Motherboard for AMD AM4 CPUs – Available on Ebay.com

Image source: Ebay.com (2019)

CPU (£500)

AMD Ryzen 9 3900X
# of CPU Cores: 12 - # of threads: 24 - Base clock: 3.8GHz - Max boost clock:
Avg. H/s 11765 – 155 Watts

Images source: AMD.com (2019)

Power plant (£300)

500W/H 12V hybrid solar wind home complete system 400W Generator 100W Mono Panel – Available on Ebay.com.

Image source: Ebay.com (2019)

Appendix C. RandomX Benchmarks

“RandomX is a proof of work (PoW) algorithm optimised for CPUs which Monero is planning to adopt via a hard-fork in order to become ASIC resistant. Below is a list of CPUs and GPUs and their average RandomX hashing performance and power usage” (RandomX 2019).

Performance and Wattage comparison of CPUs mining XMR

CPU	Cache	Cores	Benchmarks	Avg. H/s	Avg. Watts	Avg. H/Watt
AMD EPYC 7601	L2: 16 MB L3: 64 MB	32	1	13902	-	-
AMD Ryzen 9 3900X	L2: 6 MB L3: 64 MB	12	5	11765	155	75.90
AMD Ryzen Threadripper 1950X	L2: 8 MB L3: 32 MB	16	3	8527	175	48.73
Intel Xeon Gold 6138	L2: 20 MB L3: 27.5 MB	20	2	7768	-	-
AMD Ryzen 7 3700X	L2: 4 MB L3: 32 MB	8	1	7000	-	-
AMD Ryzen Threadripper 1920X	L2: 6 MB L3: 32 MB	12	1	6757	-	-
Intel Xeon Gold 6150	L2: 18 MB L3: 24.75 MB	18	1	6279	-	-
AMD Ryzen 5 3600	L2: 3 MB L3: 32 MB	6	4	6264	113	55.43
Intel Xeon E5-2687WV4	L2: 3 MB L3: 30 MB	12	1	4582	-	-
AMD Ryzen 7 1700	L2: 4 MB L3: 16 MB	8	7	4469	100	44.69

Five documented Ryzen 9 3900X benchmarks mining XMR

CPU Count	H/s	Watts	RAM	OS	Submitted	Miner	Parameters	Notes
1	12327		32 GB DDR4		2019-07-15 Source	RandomX benchmark	--mine --threads 30 --init 24 --nonces 800000 --largePages --jit	2*16Gb 3200mhz CL14, 4Ghz on all 12 cores
1	12200	180			2019-07-29 Source	RandomX benchmark		
1	11835			Linux	2019-07-10 Source	RandomX benchmark	--init 24 --threads 24 --nonces 1000 --largePages	3200 MHz CL16 RAM
1	11500	130			2019-07-29 Source	RandomX benchmark		
1	10965		16 GB DDR4	Windows 10	2019-07-27	RandomX benchmark	24 threads and init (1:1 infinity fabric to ram results in 200 h/s gain)	

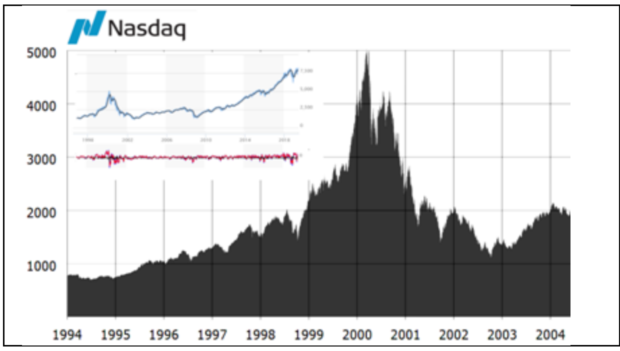
Source: RandomX Benchmarks (2019)

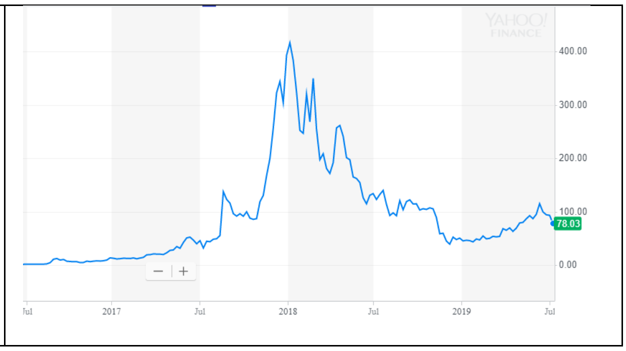
Appendix D. Economic Hyperbolic Inflations.

The dot-com and virtual currency bubble compared.

A. Nasdaq dot-com bubble (1994-2004)

B. Monero (XMR) bubble (2017-2019)





Source: Adapted from Nasdaq.com (2019) and Coinmarketcap.com (2019)

Looking at the above diagrams, it is clear from the dot-com bubble that despite the bubble bursting that the market recovered and doubled from the peak of the bubble. Future technologies that will become dominant will attract early attention, and this is apparent in the crypto-currency boom. The lesson is that despite losing significantly from the peak in 2017, crypto-currencies are starting to recover and slowly gain back previous losses.

Both the dot-com bubble and crypto-currency bubble took place over roughly the same time frame. The question is whether the crypto-currency, like the NASDAQ, will double from its previous peak.

Appendix E. Linear (additive growth) business lifecycles

Below is an example sales forecast of a linear, additive growth, product lifecycle of widgets with the input (+) / output (+) ratio remaining relatively equal as the business scales.

The advantage of this system is that through a scientific business model, reducing costs through manufacturing allows sufficient margin between variable costs and sales price to fund operations and growth (citation). The disadvantage of this system is that as a business scales upward, the ratio of input / output remains relatively stable over time. Franchises rely on this fact. The energy requirements of one Nandos restaurant will be the same for another. However, this also means that as a company grows, so does its cumulative damage to the environment.

Table 3. Sales forecast of Widget Producers Ltd.

Month	Unit Sales	Sale Price (£)	Revenue ('000£)
Jan	5	10	50
Feb	10	9	90
Mar	15	8	120
Apr	20	8	160
May	25	7	175
Jun	30	6	180
Jul	35	5	175
Aug	40	5	200
Sep	45	5	225
Oct	50	4	200

Figure 4. Product revenue through discounts and growing sales.

Source: Author's creation.

As quantity of units sold increases prices decrease to encourage more purchasing throughout the entire lifecycle of the product, rather than tapering off with a normal bell curve distribution lifecycle. Price equilibrium is determined partly by the marketplace and partly due to a growth factor of 10 in sales volume allowing a discount of up to 60% toward the end of the 10 months period with revenue near its peak at the end of the product lifecycle.

Linear growth is the classic economic model of business and demonstrates the input (+) / output (+) ratio of COGS + Revenue, with prices decreasing as quantity of sales increase (assuming supply is scalable).

Appendix F. Key Bitcoin Network Statistics

Description	Value
Bitcoin's current estimated annual electricity consumption* (TWh)	73.12
Bitcoin's current minimum annual electricity consumption** (TWh)	48.8
Annualized global mining revenues	$7,430,140,088
Annualized estimated global mining costs	$3,656,073,069
Current cost percentage	49.21%
Country closest to Bitcoin in terms of electricity consumption	Austria
Estimated electricity used over the previous day (KWh)	200,332,771
Implied Watts per GH/s	0.092
Total Network Hashrate in PH/s (1,000,000 GH/s)	91,044
Energy footprint per transaction (KWh)	603
Number of U.S. households that could be powered by Bitcoin	6,770,506
Number of U.S. households powered for 1 day by the electricity consumed for a single transaction	20.38
Bitcoin's electricity consumption as a percentage of the world's electricity consumption	0.33%
Annual carbon footprint (kt of CO2)	34,733
Carbon footprint per transaction (kg of CO2)	286.48

*The assumptions underlying this energy consumption estimate can be found here. Criticism and potential validation of the estimate is discussed here.
**The minimum is calculated from the total network hashrate, assuming the only machine used in the network is Bitmain's Antminer S9 (drawing 1,500 watts each). On February 13, 2019, the minimum benchmark was changed to Bitmain's Antminer S15 (with a rolling average of 180 days).

Source: Digiconomist.net (2019)

Appendix

[i] "The environmental risks of large-scale commercial shale gas development in the United States include water consumption, water contamination, seismic inducement and air pollution" (Zhang and Yang 2015).
[ii] The next stage in research is building a model prototype system to the specifications outlined in this paper and mining for three years, the typical lifecycle, in order to test the predictions in this paper or to explain why there are any unexpected deviations.
[iii] Other alternative energy sources can be used and see the same benefits; however, there are different logistics for each source, as well as slightly different start-up and maintenance costs which would need to be considered before going forward.
[iv] Blockchain difficulty is also positively correlated with the effectiveness of mining with CPUs, as it protects against ASICs.
[v] Profits are net profits (before equipment costs). In addition, this does not take into consideration changing market conditions, nor increases in the difficulty algorithm, all of which can have an effect on quantity and value of the total coins earned.
[vi] Benchmarking studies and AMD's own website appear to disagree as to whether the power requirements are 105 Watts (according to AMD) or 155 Watts (according to real-world testing). The cooling capacity, however, is sufficiently above 155 Watts, thereby making either case sufficiently within heat dissipation capabilities.
[vii] Maxwell's Equations observe that electromagnetic radiation, i.e. electricity, behaves as a wave (Chirgwin, Plumpton and Kilmister, 2014). The implications are that the higher the frequency potential of the CPU, the higher its mining potential. (Dennard scaling states that in order to process higher frequencies at lower energy levels, the CPU must be reduced in size). And so, whilst frequency does add energy to electromagnetic radiation, other factors such as amplitude, can have a much higher impact: "The energy of a wave is not just a matter of frequency. For two waves of the same amplitude the higher frequency will have higher energy content because the medium is vibrating at faster speeds and its particles have higher kinetic energy. Frequencies do not add and do not change as waves travel through (linear) media. But waves also have amplitude and amplitudes add up when waves combine. Many little waves can add to become arbitrarily large waves, something surfers well understand. Loud low frequency sounds can have more energy than soft high frequency sounds. A very bright red light can have more energy than a dim blue light even though blue light has higher frequency and therefore is more energetic than red light" (Bruni 2017).
[viii] Net Systems Value (NSV) is proposed in this paper as a better way to measure the true value of a company when long-term costs to the environment are factored in.
[ix] The carbon credit system is an economisation of NSV with the theory that improvements to the system overall, however unevenly distributed, will result in net improvements to the environment.